FIG.1A

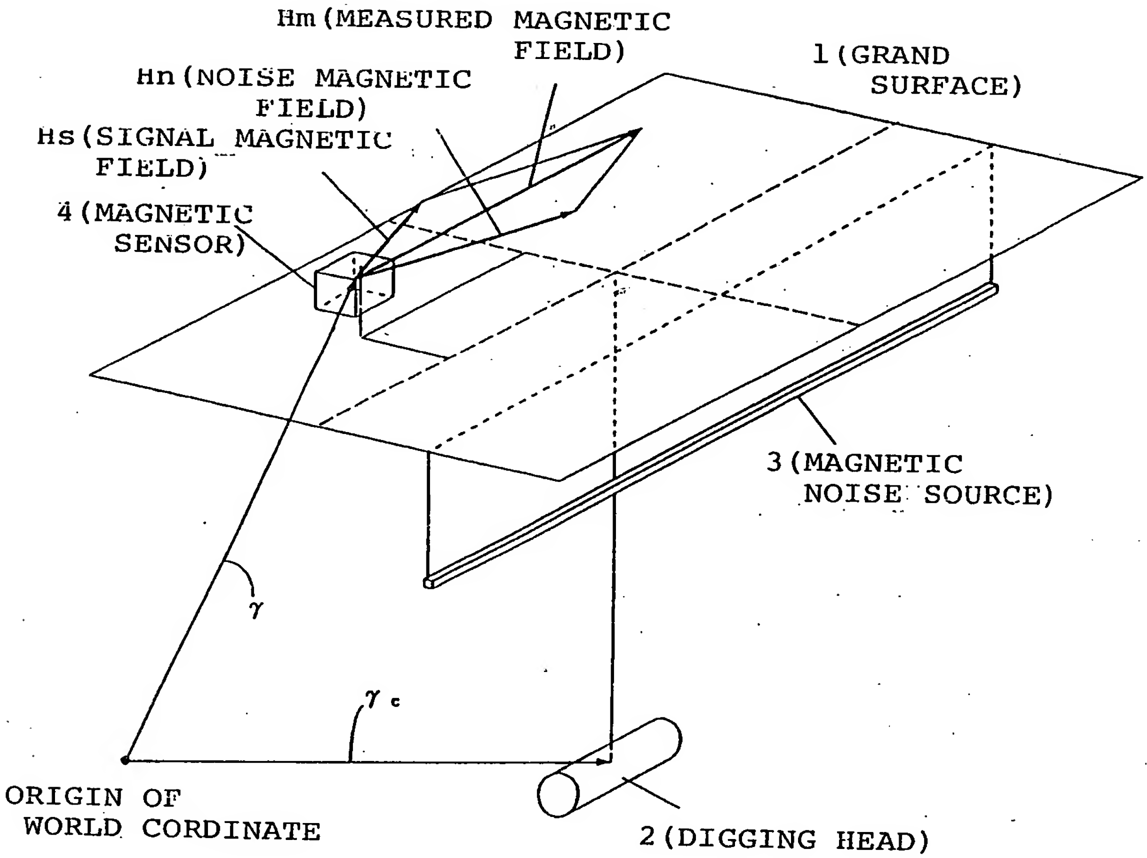

Hm(MEASURED MAGNETIC FIELD)
Hn(NOISE MAGNETIC FIELD)
Hs(SIGNAL MAGNETIC FIELD)
4(MAGNETIC SENSOR)
1(GRAND SURFACE)
3(MAGNETIC NOISE SOURCE)
γ
γ c
ORIGIN OF WORLD CORDINATE
2(DIGGING HEAD)

FIG.1B

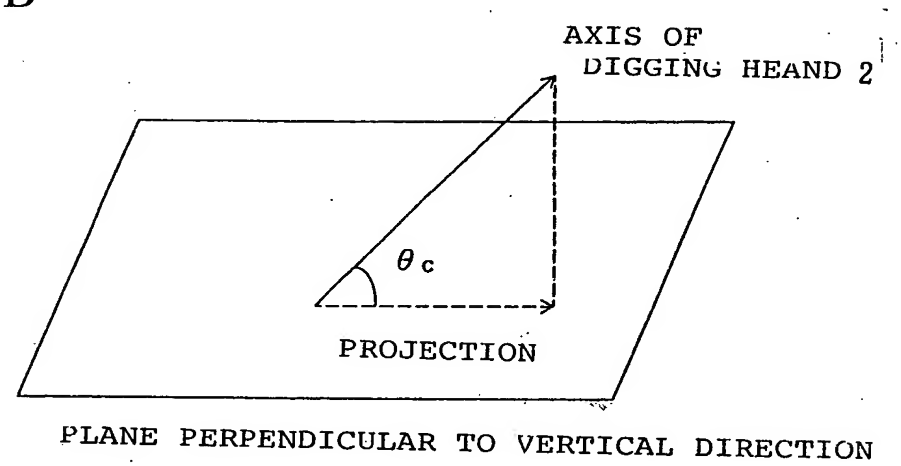
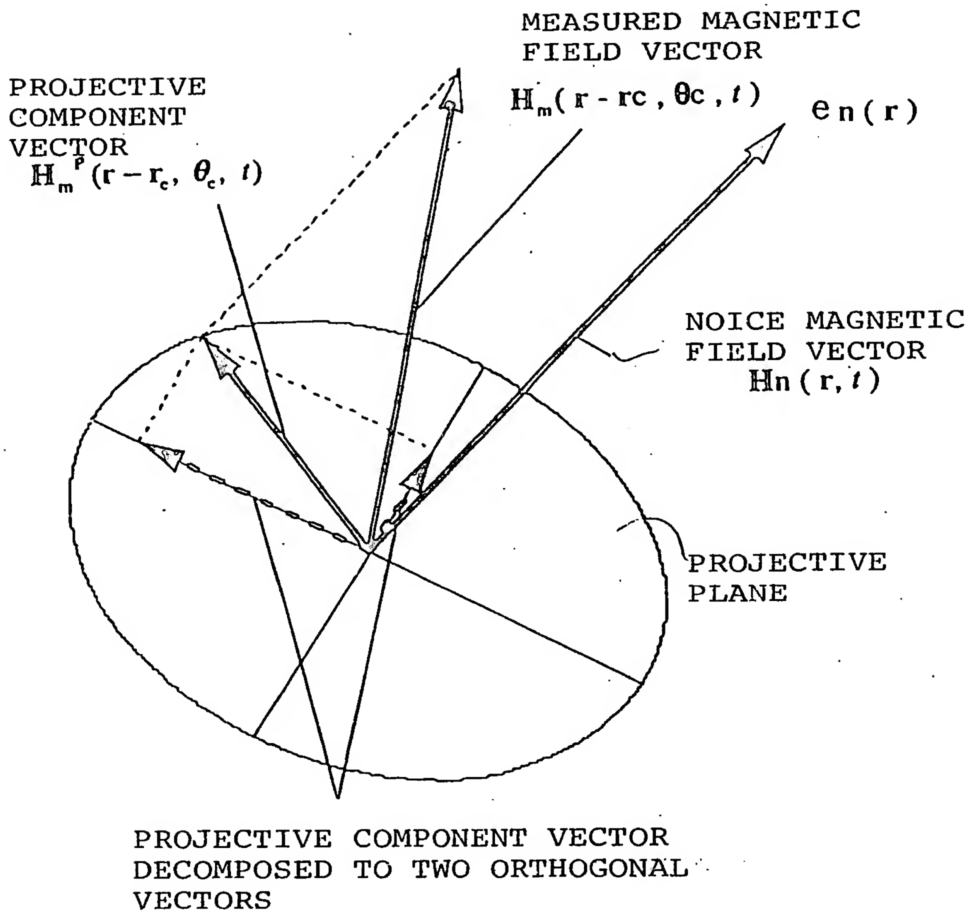

AXIS OF DIGGING HEAND 2
θ c
PROJECTION
PLANE PERPENDICULAR TO VERTICAL DIRECTION

FIG.2


MEASURED MAGNETIC FIELD VECTOR
$H_m(r - rc, \theta c, t)$
PROJECTIVE COMPONENT VECTOR
$H_m^P(r - r_c, \theta_c, t)$
$e_n(r)$
NOICE MAGNETIC FIELD VECTOR
$Hn(r, t)$
PROJECTIVE PLANE
PROJECTIVE COMPONENT VECTOR DECOMPOSED TO TWO ORTHOGONAL VECTORS

10006742.110402

FIG.3

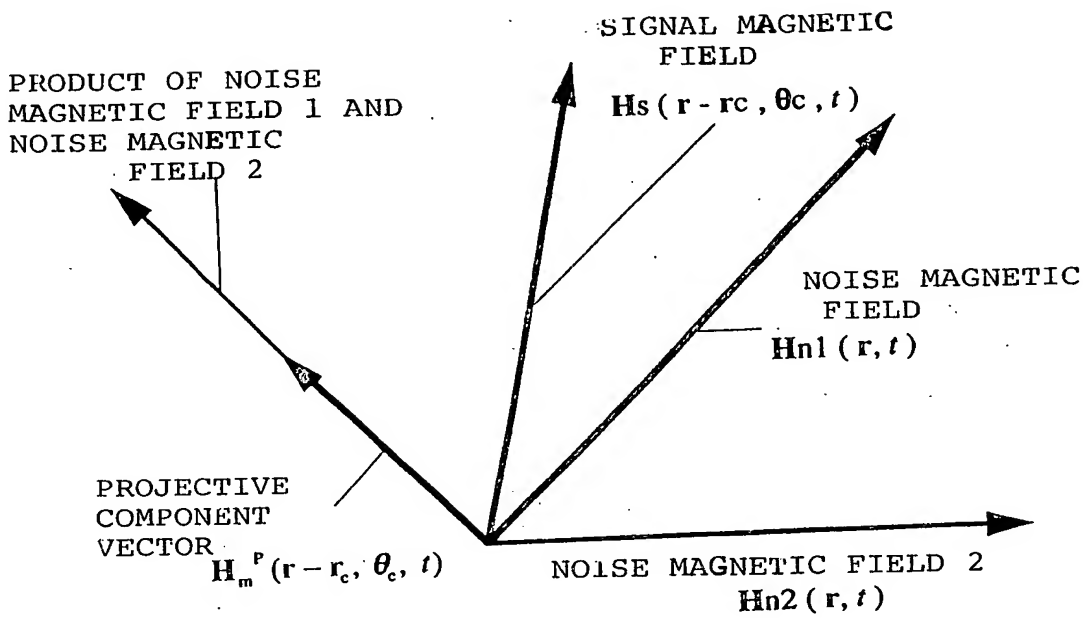


FIG.4

CALCULATION OF PROJECTIVE COMPONENT VECTOR STARTS

S1

OBTAINING OF MEASURED MAGNETIC FIELD VECTOR: MAGNECTIC FIELD MIXED WITH NOISE MAGNETC FIELD IS MEASURED

S2

MEASURED MAGNECTIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM

S3

CALCULATION OF PROJECTIVE COMPONENT VECTOR

$$\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=$$

$$\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)-(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_n(\mathbf{r}))\mathbf{e}_n(\mathbf{r}).$$

S4

CALCULATION OF TWO INDEPENDENT COMPONENTS OF PROJECTIVE COMPONENT VECTOR

$$H_{m,1}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_{p,1}.$$

$$\mathbf{e}_{p,1}=\mathbf{e}_m\times\mathbf{e}_n(\mathbf{r}).$$

$$H_{m,2}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot\mathbf{e}_{p,2}.$$

$$\mathbf{e}_{p,2}=\mathbf{e}_{p,1}\times\mathbf{e}_n(\mathbf{r}).$$

CALCULATION OF PROJECTIVE COMPONENT VECTOR ENDS

FIG.5

CALCULATION OF PROJECTIVE COMPONENT VECTOR STARTS

S11

OBTAINING OF MEASURED MAGNETIC FIELD VECTOR: MAGNETIC FIELD MIXED WITH NOISE MAGNETIC FIELD IS MEASURED

S12

MEASURED MAGNETIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM

S13

CALCULATION OF PROJECTIVE COMPONENT VECTOR

$$\mathbf{e}_N(\mathbf{r}) = \mathbf{e}_{n1}(\mathbf{r}) \times \mathbf{e}_{n2}(\mathbf{r}).$$

$$\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) =$$

$$\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) - (\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) \cdot \mathbf{e}_N(\mathbf{r}))\mathbf{e}_N(\mathbf{r}).$$

CALCULATION OF PROJECTIVE COMPONENT VECTOR ENDS

FIG.6

CALCULATION OF SIGNAL COMPONENT VECTOR STARTS

S11

OBTAINING OF MEASURED MAGNETIC FIELD VECTOR: MAGNETIC FIELD MIXED WITH NOISE MAGNETIC FIELD IS MEASURED

S12

MEASURED MAGNETIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM

S14

CALCULATION OF PROJECTIVE COMPONENT VECTOR

$$\mathbb{H}_m^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=$$

$$\mathbb{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)-(\mathbb{H}_m(\mathbf{r}-\mathbf{r}_o,\ \theta_o,\ t)\cdot\mathbf{e}_n(\mathbf{r}))\mathbf{e}_n(\mathbf{r}).$$

S15

CALCULATION OF TWO INDEPENDENT COMPONENTS OF PROJECTIVE COMPONENT VECTOR

$$H_{m,1}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=\mathbb{H}_m^P(\mathbf{r}-\mathbf{r}_o,\ \theta_o,\ t)\cdot\mathbf{e}_{p,1}.$$

$$\mathbf{e}_{p,1}=\mathbf{e}_m\times\mathbf{e}_n(\mathbf{r}).$$

$$H_{m,2}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)=\mathbb{H}_m^P(\mathbf{r}-\mathbf{r}_o,\ \theta_o,\ t)\cdot\mathbf{e}_{p,2}.$$

$$\mathbf{e}_{p,2}=\mathbf{e}_{p,1}\times\mathbf{e}_n(\mathbf{r}).$$

S16

CALCULATION OF SIGNAL COMPONENT VECTOR

$$\mathbb{H}_s(\mathbf{r}-\mathbf{r}_o,\ \theta_c)=\left\langle\mathbb{H}_m(\mathbf{r}-\mathbf{r}_o,\cdot\theta_c,\ t)H_m^P(\mathbf{r}-\mathbf{r}_o,\ \theta_o,\ t)\right\rangle_t.$$

CALCULATION OF SIGNAL COMPONENT VECTOR ENDS

FIG.7

CALCULATION OF SIGNAL COMPONENT VECTOR STARTS

S11

OBTAINING OF MEASURED MAGNETIC FIELD VECTORS: MAGNETIC FIELD MIXED WITH NOISE MAGNETIC FIELD IS MEASURED

S12

MEASURED MAGNETIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM

S14a

CALCULATION OF PROJECTIVE COMPONENT VECTOR

$$\mathbf{e}_N(\mathbf{r}) = \mathbf{e}_{n1}(\mathbf{r}) \times \mathbf{e}_{n2}(\mathbf{r}).$$

$$\mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) =$$

$$\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) - (\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot \mathbf{e}_N(\mathbf{r}))\mathbf{e}_N(\mathbf{r}).$$

S16

CALCULATION OF SIGNAL COMPONENT VECTOR

$$\mathbf{H}_s(\mathbf{r}-\mathbf{r}_c,\ \theta_c) = \left\langle \mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) H_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right\rangle_t.$$

CALCULATION OF SIGNAL COMPONENT VECTOR ENDS

FIG.8

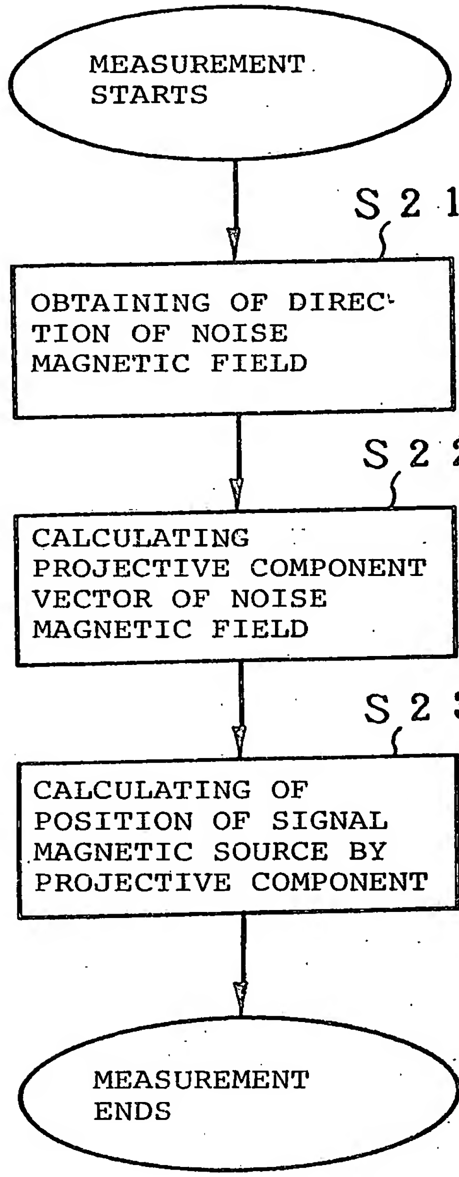

MEASUREMENT STARTS
S21
OBTAINING OF DIRECTION OF NOISE MAGNETIC FIELD
S22
CALCULATING PROJECTIVE COMPONENT VECTOR OF NOISE MAGNETIC FIELD
S23
CALCULATING OF POSITION OF SIGNAL MAGNETIC SOURCE BY PROJECTIVE COMPONENT
MEASUREMENT ENDS

FIG.9

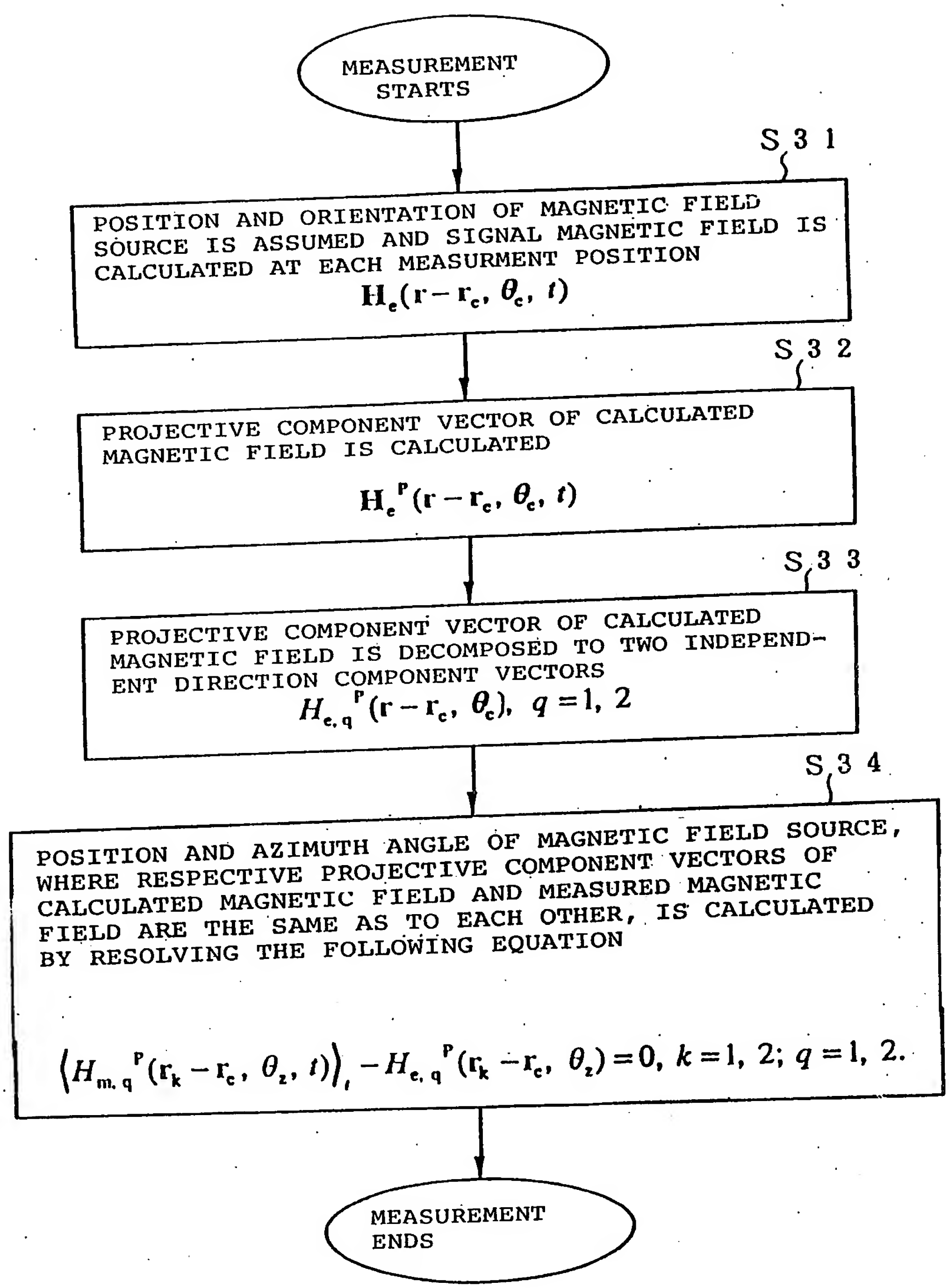

MEASUREMENT STARTS
S31
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION
$\mathbf{H}_e(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S32
PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED
$\mathbf{H}_e^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S33
PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS DECOMPOSED TO TWO INDEPEND-ENT DIRECTION COMPONENT VECTORS
$H_{e,q}^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c),\ q=1,\ 2$
S34
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE RESPECTIVE PROJECTIVE COMPONENT VECTORS OF CALCULATED MAGNETIC FIELD AND MEASURED MAGNETIC FIELD ARE THE SAME AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATION
$\left\langle H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z,\ t)\right\rangle_t - H_{e,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z)=0,\ k=1,\ 2;\ q=1,\ 2.$
MEASUREMENT ENDS

FIG.10

MEASUREMENT STARTS

↓

S41

POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION

$$\mathbf{H}_e(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$$

↓

S42

PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED

$$\mathbf{H}_e^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$$

↓

S43

PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS DECOMPOSED TO TWO INDEPENDENT DIRECTION COMPONENT VECTORS

$$H_{e,q}^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c),\ q=1,\ 2$$

↓

S44

POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE RESPECTIVE PROJECTIE COMPONENT VECTORS OF CALCULATED MAGNETIC FIELD AND MEASURED MAGNETIC FIELD ARE THE SAME AS TO EACH OTHER, IS CALCULATED BY RESILVING THE FOLLOWING EQUATION

$$\min_{\mathbf{r}_c,\ \theta_c}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\left\langle H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right\rangle_t - H_{e,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c)\right|\right\}.$$

or

$$\min_{\mathbf{r}_c,\ \theta_c}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\sqrt{\left\langle\left|H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right|^2\right\rangle_t} - H_{e,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c)\right|\right\}.$$

or

$$\min_{\mathbf{r}_c,\ \theta_z}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\left\langle H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right\rangle_t - H_{e,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z)\right|^2\right\}.$$

or

$$\min_{\mathbf{r}_c,\ \theta_z}\left\{\sum_{k=1}^{N_m}\sum_{q=1}^{2} w_{k,q}\left|\sqrt{\left\langle\left|H_{m,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right|^2\right\rangle_t} - H_{e,q}^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_z)\right|^2\right\}.$$

↓

MEASUREMENT ENDS

FIG.11

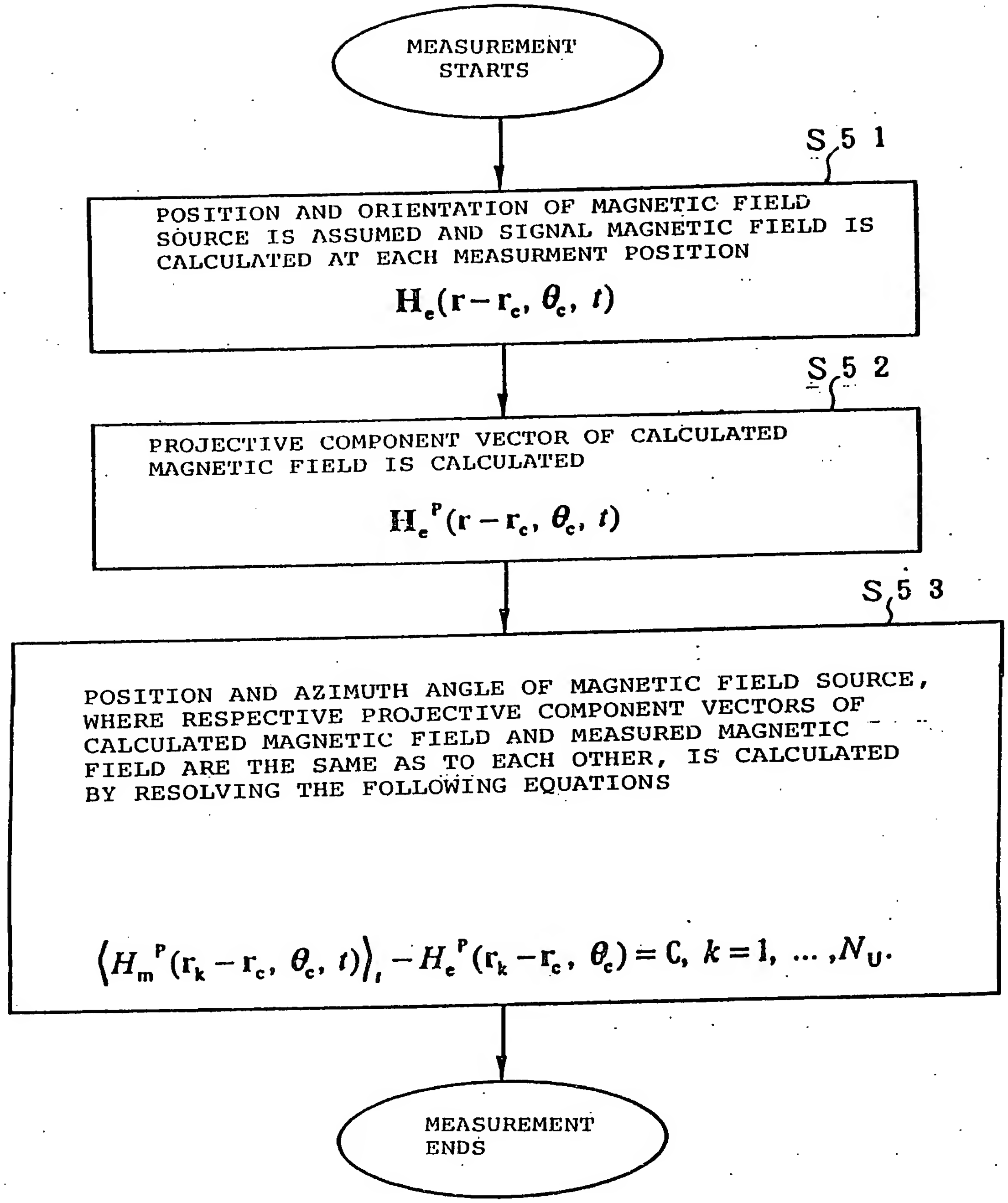

MEASUREMENT STARTS
S51
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION
$\mathbf{H}_e(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S52
PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED
$\mathbf{H}_e^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S53
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE RESPECTIVE PROJECTIVE COMPONENT VECTORS OF CALCULATED MAGNETIC FIELD AND MEASURED MAGNETIC FIELD ARE THE SAME AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATIONS
$\left\langle H_m^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ t)\right\rangle_t - H_e^{P}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c) = C,\ k=1,\ \ldots,N_U.$
MEASUREMENT ENDS

FIG.12

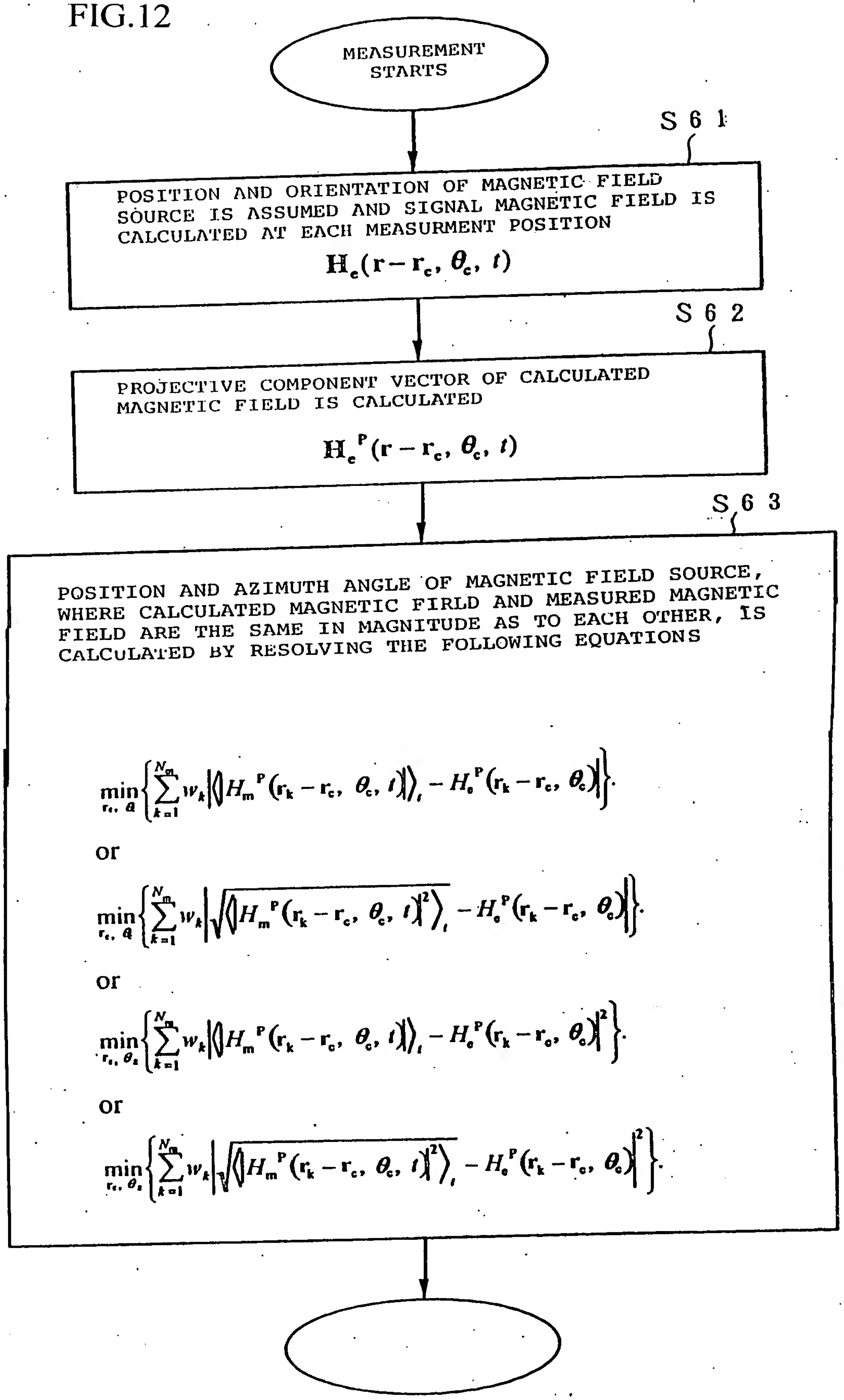

MEASUREMENT STARTS
S61
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION
$\mathbf{H}_e(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S62
PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED
$\mathbf{H}_e^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)$
S63
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE CALCULATED MAGNETIC FIRLD AND MEASURED MAGNETIC FIELD ARE THE SAME IN MAGNITUDE AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATIONS
$\min_{r_c,\theta_c}\left\{\sum_{k=1}^{N_m} w_k\left|\langle H_m^P(r_k-r_c,\ \theta_c,\ t)\rangle_t - H_e^P(r_k-r_c,\ \theta_c)\right|\right\}$
or
$\min_{r_c,\theta_c}\left\{\sum_{k=1}^{N_m} w_k\left|\sqrt{\langle |H_m^P(r_k-r_c,\ \theta_c,\ t)|^2\rangle_t} - H_e^P(r_k-r_c,\ \theta_c)\right|\right\}$
or
$\min_{r_c,\theta_c}\left\{\sum_{k=1}^{N_m} w_k\left|\langle H_m^P(r_k-r_c,\ \theta_c,\ t)\rangle_t - H_e^P(r_k-r_c,\ \theta_c)\right|^2\right\}$
or
$\min_{r_c,\theta_c}\left\{\sum_{k=1}^{N_m} w_k\left|\sqrt{\langle |H_m^P(r_k-r_c,\ \theta_c,\ t)|^2\rangle_t} - H_e^P(r_k-r_c,\ \theta_c)\right|^2\right\}$

FIG.13

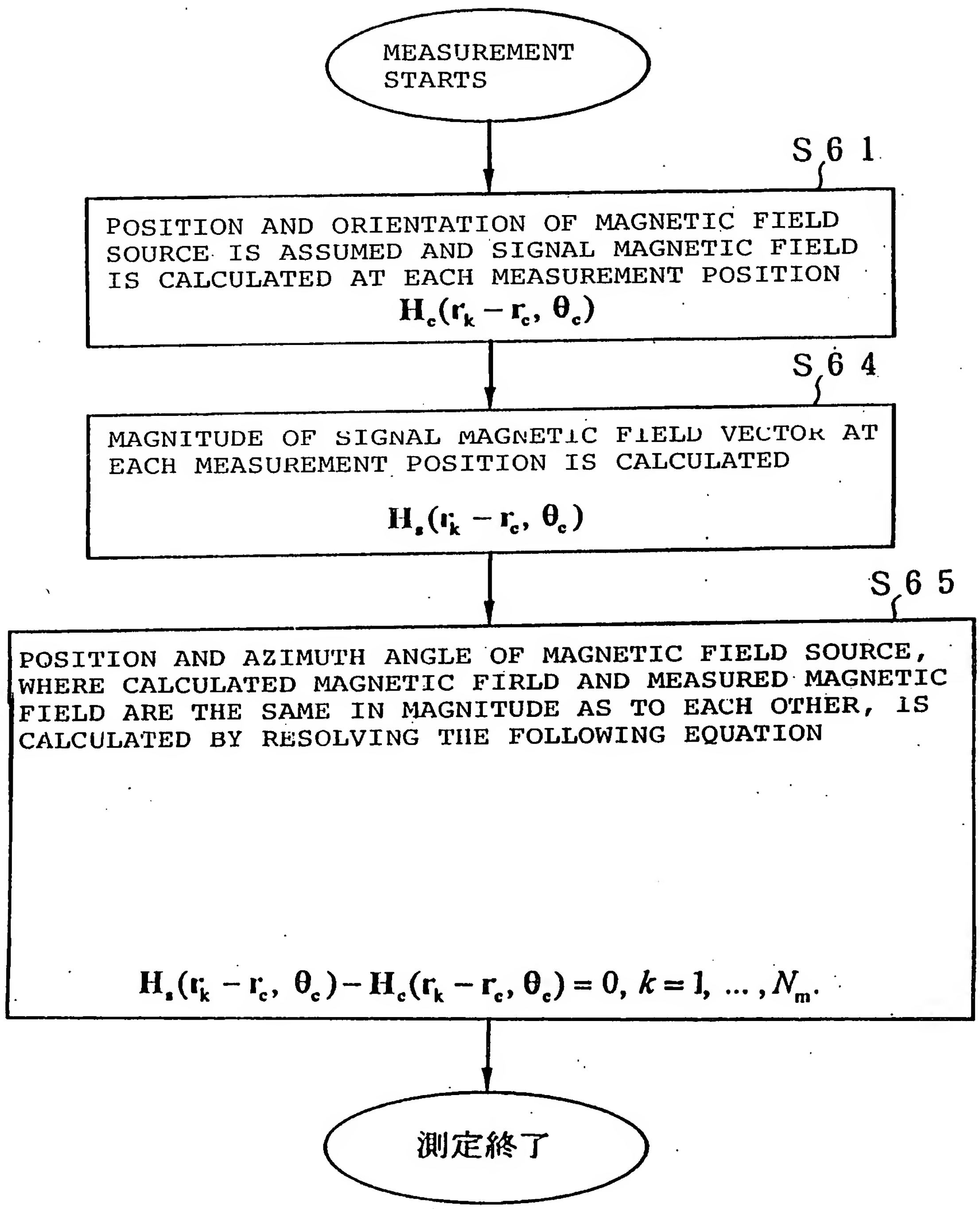

MEASUREMENT STARTS
S61
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASUREMENT POSITION
$\mathbf{H}_c(\mathbf{r}_k - \mathbf{r}_c, \theta_c)$
S64
MAGNITUDE OF SIGNAL MAGNETIC FIELD VECTOR AT EACH MEASUREMENT POSITION IS CALCULATED
$\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_c, \theta_c)$
S65
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE CALCULATED MAGNETIC FIRLD AND MEASURED MAGNETIC FIELD ARE THE SAME IN MAGNITUDE AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATION
$\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_c, \theta_c) - \mathbf{H}_c(\mathbf{r}_k - \mathbf{r}_c, \theta_c) = 0,\ k = 1, \ldots, N_m.$
測定終了

FIG.14

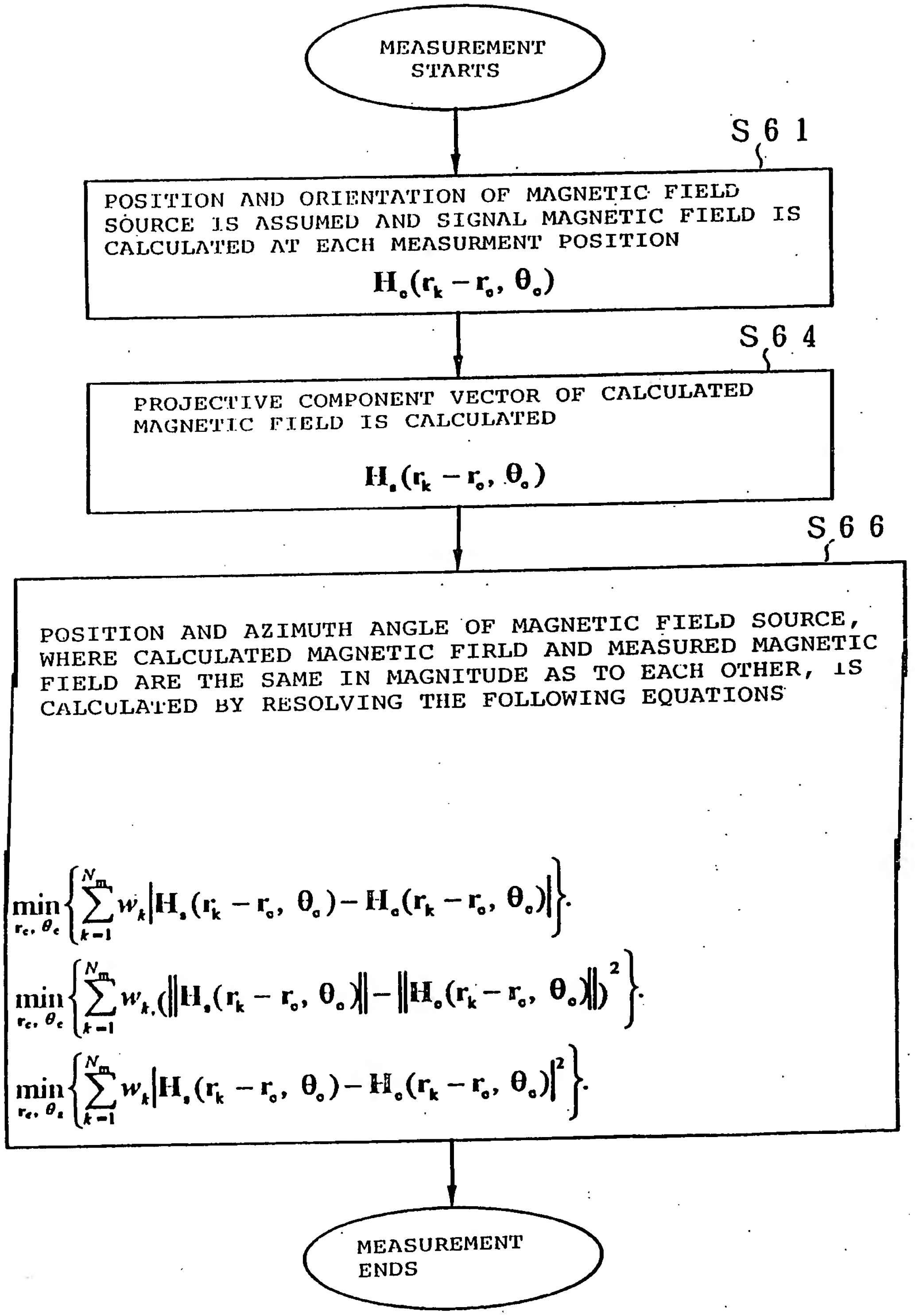

MEASUREMENT STARTS
S61
POSITION AND ORIENTATION OF MAGNETIC FIELD SOURCE IS ASSUMED AND SIGNAL MAGNETIC FIELD IS CALCULATED AT EACH MEASURMENT POSITION
$\mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o, \theta_o)$
S64
PROJECTIVE COMPONENT VECTOR OF CALCULATED MAGNETIC FIELD IS CALCULATED
$\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o, \theta_o)$
S66
POSITION AND AZIMUTH ANGLE OF MAGNETIC FIELD SOURCE, WHERE CALCULATED MAGNETIC FIRLD AND MEASURED MAGNETIC FIELD ARE THE SAME IN MAGNITUDE AS TO EACH OTHER, IS CALCULATED BY RESOLVING THE FOLLOWING EQUATIONS
$\min_{r_c, \theta_c}\left\{\sum_{k=1}^{N_m} w_k \left|\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o, \theta_o) - \mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o, \theta_o)\right|\right\}.$
$\min_{r_c, \theta_c}\left\{\sum_{k=1}^{N_m} w_k \left(\left\|\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o, \theta_o)\right\| - \left\|\mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o, \theta_o)\right\|\right)^2\right\}.$
$\min_{r_c, \theta_c}\left\{\sum_{k=1}^{N_m} w_k \left|\mathbf{H}_s(\mathbf{r}_k - \mathbf{r}_o, \theta_o) - \mathbf{H}_o(\mathbf{r}_k - \mathbf{r}_o, \theta_o)\right|^2\right\}.$
MEASUREMENT ENDS

FIG.15

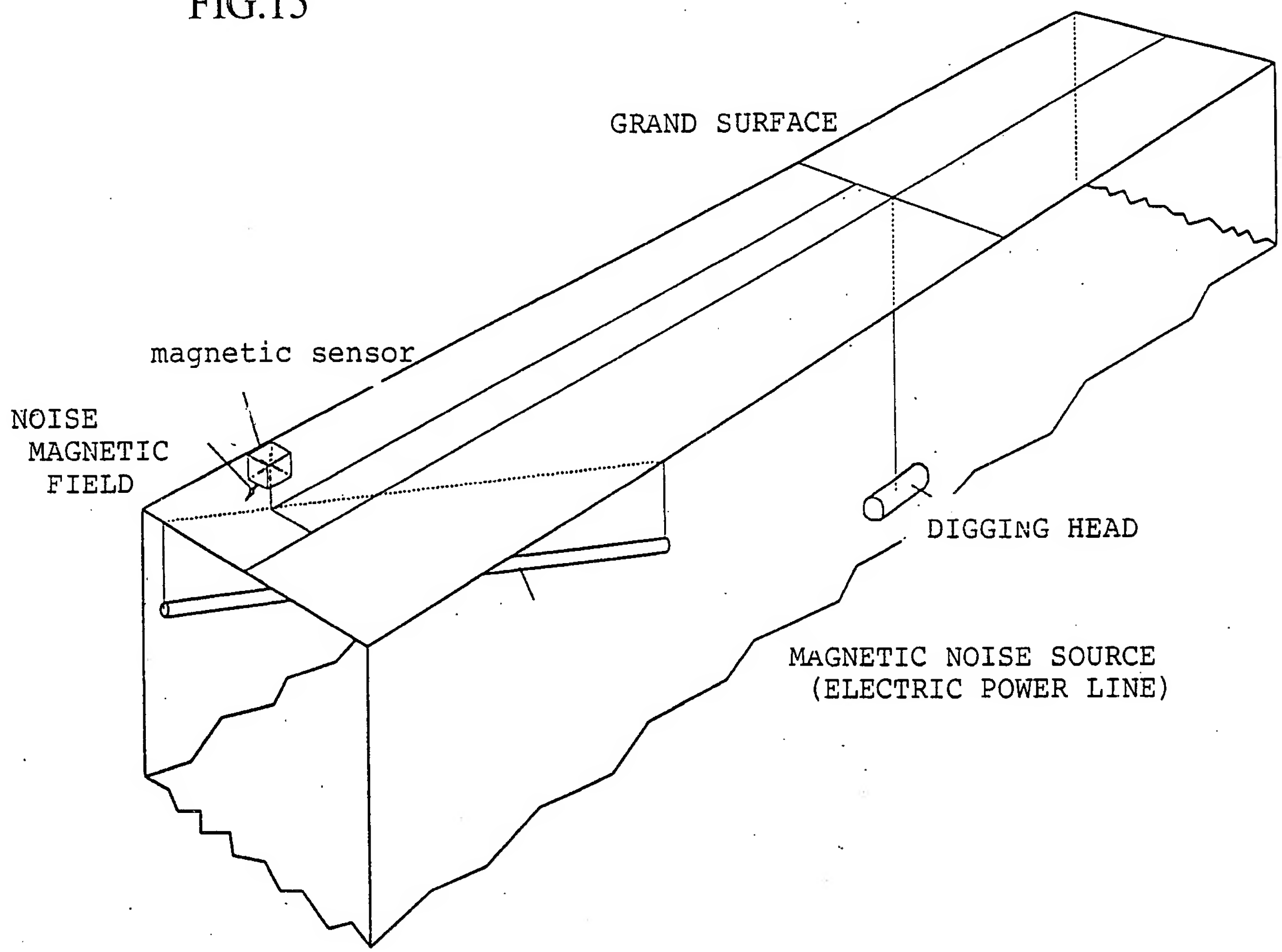

GRAND SURFACE
magnetic sensor
NOISE MAGNETIC FIELD
DIGGING HEAD
MAGNETIC NOISE SOURCE (ELECTRIC POWER LINE)

FIG.16

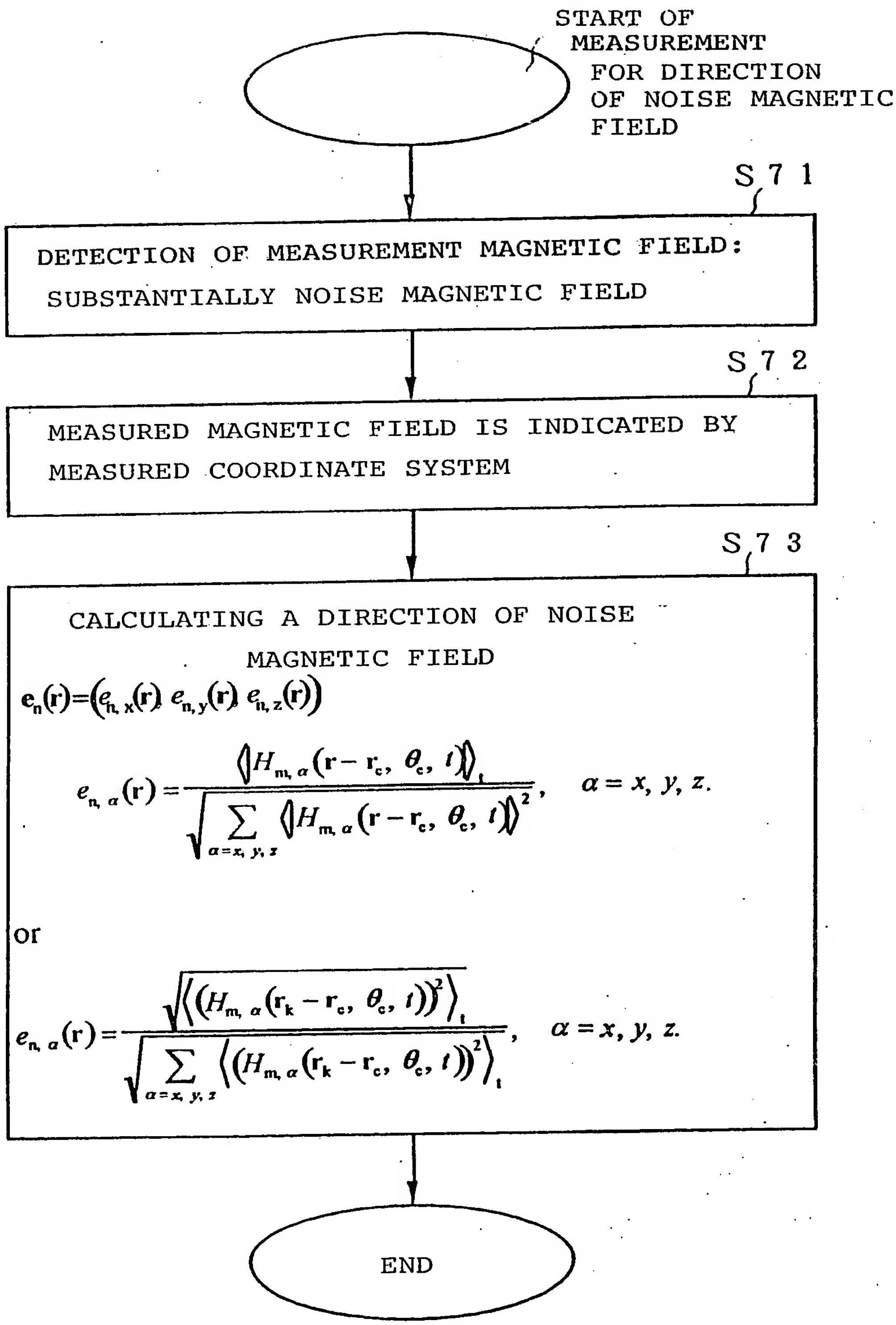

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD
S71
DETECTION OF MEASUREMENT MAGNETIC FIELD: SUBSTANTIALLY NOISE MAGNETIC FIELD
S72
MEASURED MAGNETIC FIELD IS INDICATED BY MEASURED COORDINATE SYSTEM
S73
CALCULATING A DIRECTION OF NOISE MAGNETIC FIELD
$\mathbf{e}_n(\mathbf{r}) = \left(e_{n,x}(\mathbf{r})\ e_{n,y}(\mathbf{r})\ e_{n,z}(\mathbf{r})\right)$
$e_{n,\alpha}(\mathbf{r}) = \dfrac{\left\langle H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c, \theta_c, t)\right\rangle_t}{\sqrt{\sum_{\alpha=x,y,z}\left\langle H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c, \theta_c, t)\right\rangle^2}}, \quad \alpha = x, y, z.$
or
$e_{n,\alpha}(\mathbf{r}) = \dfrac{\sqrt{\left\langle \left(H_{m,\alpha}(\mathbf{r}_k-\mathbf{r}_c, \theta_c, t)\right)^2\right\rangle_t}}{\sqrt{\sum_{\alpha=x,y,z}\left\langle \left(H_{m,\alpha}(\mathbf{r}_k-\mathbf{r}_c, \theta_c, t)\right)^2\right\rangle_t}}, \quad \alpha = x, y, z.$
END

FIG.17

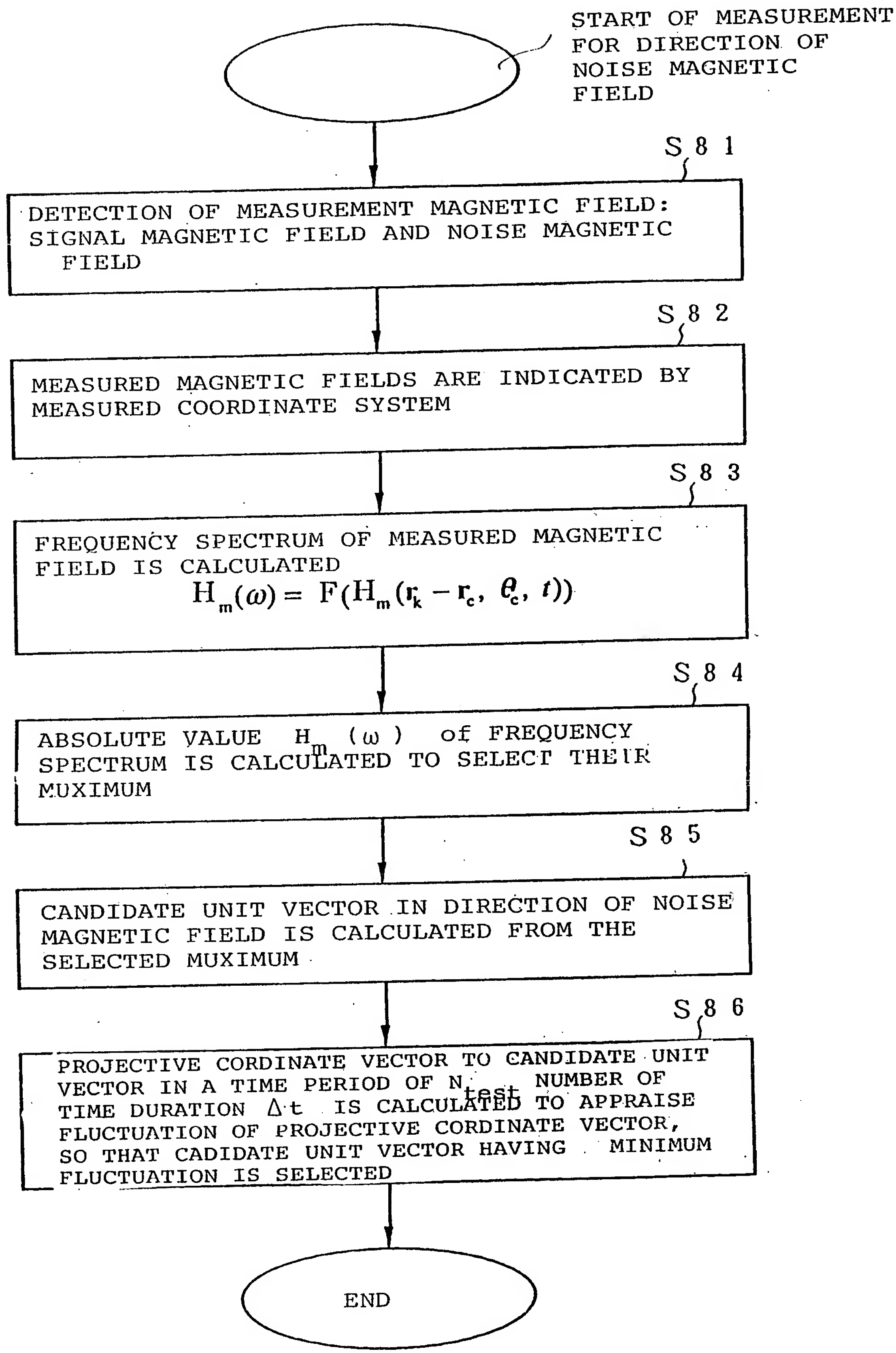

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD
S81
DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD
S82
MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM
S83
FREQUENCY SPECTRUM OF MEASURED MAGNETIC FIELD IS CALCULATED
$H_m(\omega) = F(H_m(r_k - r_c, \theta_c, t))$
S84
ABSOLUTE VALUE $H_m(\omega)$ of FREQUENCY SPECTRUM IS CALCULATED TO SELECT THEIR MUXIMUM
S85
CANDIDATE UNIT VECTOR IN DIRECTION OF NOISE MAGNETIC FIELD IS CALCULATED FROM THE SELECTED MUXIMUM
S86
PROJECTIVE CORDINATE VECTOR TO CANDIDATE UNIT VECTOR IN A TIME PERIOD OF N_{test} NUMBER OF TIME DURATION Δt IS CALCULATED TO APPRAISE FLUCTUATION OF PROJECTIVE CORDINATE VECTOR, SO THAT CADIDATE UNIT VECTOR HAVING MINIMUM FLUCTUATION IS SELECTED
END

FIG.18

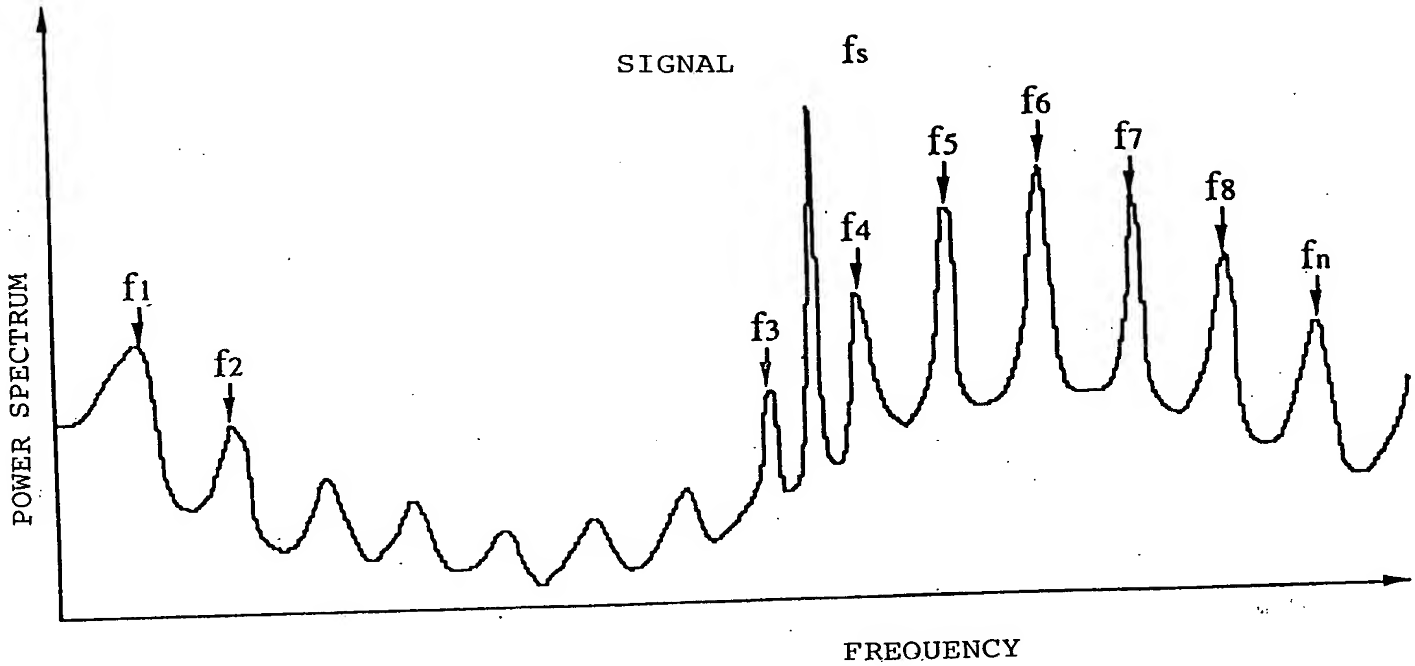

SIGNAL
fs
f1
f2
f3
f4
f5
f6
f7
f8
fn
POWER SPECTRUM
FREQUENCY

FIG.19

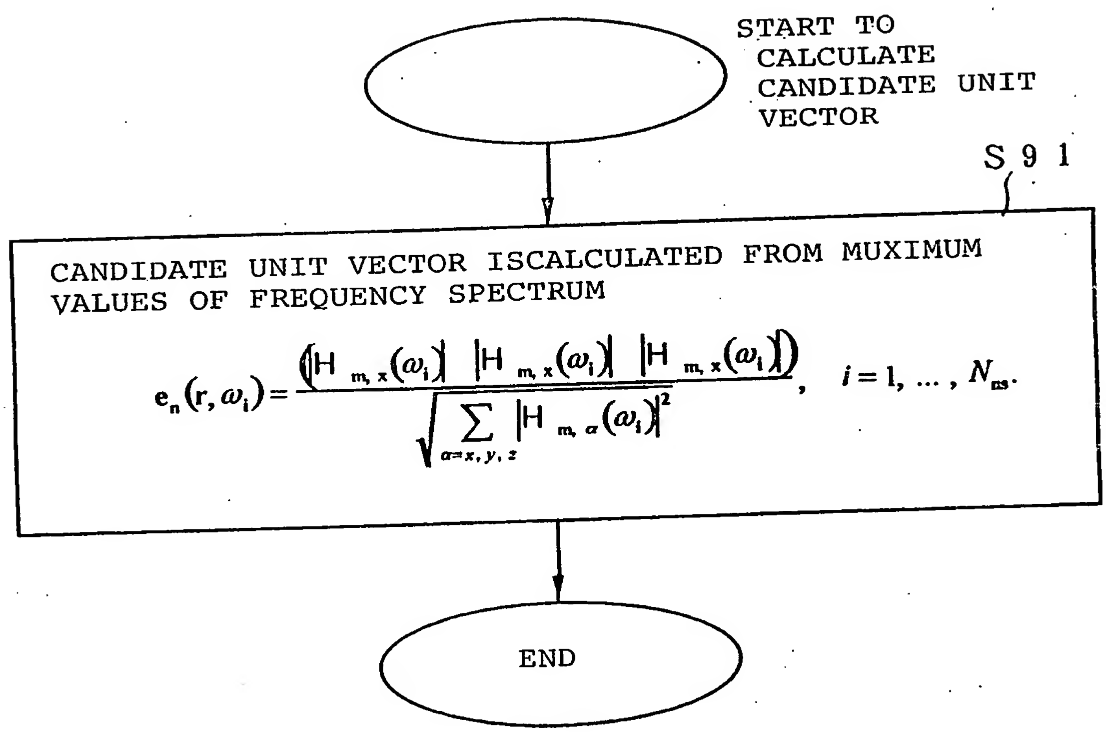

START TO CALCULATE CANDIDATE UNIT VECTOR
S 9 1
CANDIDATE UNIT VECTOR ISCALCULATED FROM MUXIMUM VALUES OF FREQUENCY SPECTRUM
$$e_n(r,\omega_i)=\frac{\left(\left|H_{m,x}(\omega_i)\right|\ \left|H_{m,x}(\omega_i)\right|\ \left|H_{m,x}(\omega_i)\right|\right)}{\sqrt{\sum_{\alpha=x,y,z}\left|H_{m,\alpha}(\omega_i)\right|^2}},\quad i=1,\ldots,N_{ns}.$$
END

FIG.20

START TO CALCULATE CANDIDATE UNIT VECTOR

S101

FROM MUXIMUM VALUES OF FREQUENCY SPECTRUM DERIVED BY FILTERING AT CORRESPONDING CENTER FREQUENCY, CORRESPONDING FREQUENCY COMPONENTS IN THE MEASURED MAGNETIC FIELD

S102

FROM FREQUENCY COMPONENTS DERIVED BY FILTERING, CANDIDATE UNIT VECTOR

$$\mathbf{e}_n(\mathbf{r}) = \left(e_{n,x}(\mathbf{r}),\ e_{n,y}(\mathbf{r}),\ e_{n,z}(\mathbf{r})\right)$$

ARE CALCULATED BY ANY OF FOLLOWING PROCEDURES

$$e_{n,\alpha}(\mathbf{r},\ \omega_i) = \frac{\left\langle \left| H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right| \right\rangle_t}{\sqrt{\sum_{\alpha=x,y,z} \left\langle \left| H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right| \right\rangle^2}},$$

$$\alpha = x,\ y,\ z;\ i = 1,\ \ldots,\ N_{ms}.$$

OR

$$e_{n,\alpha}(\mathbf{r},\ \omega_i) = \frac{\sqrt{\left\langle \left(H_{m,x}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right)^2 \right\rangle_t}}{\sqrt{\sum_{\alpha=x,y,z} \left\langle \left(H_{m,\alpha}(\mathbf{r}_k-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) \right)^2 \right\rangle_t}},$$

$$\alpha = x,\ y,\ z;\ i = 1,\ \ldots,\ N_{ms}.$$

END

FIG.21

START TO CALCULATE DIRECTION OF NOISE MAGNETIC FIELD

S111

PROJECTIVE CORDINATE VECTOR TO CANDIDATE UNIT VECTOR IN A TIME PERIOD OF N_{test} NUMBER OF TIME DURATION Δt IS CALCULATED

$$\mathbf{H}_m^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t) = \mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t) - (\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\cdot \mathbf{e}_n(\mathbf{r},\ \omega_i))\mathbf{e}_n(\mathbf{r},\ \omega_i),\ i=1,\ \dots,\ N_{ns}.$$

S112

VARIATION OF PROJECTIVE COMPONENT

$v_{eval,k}(\omega_i),\ k=1,\ \dots,\ N_{test}$

$$v_{eval,k}(\omega_i) = \left\langle\left| H_{m,q}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t)\right|\right\rangle_{T_{t,k}},\ q=1,\ 2;\ k=1,\ \dots,\ N_{test};\ i=1,\ \dots,\ N_{ns}.$$

OR

$$v_{eval,k}(\omega_i) = \left\langle\left| \mathbf{H}_m{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t)\right|\right\rangle_{T_{t,k}},\ k=1,\ \dots,\ N_{test};\ i=1,\ \dots,\ N_{ns}.$$

OR

$$v_{eval,k}(\omega_i) = \left\langle (H_{m,q}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t))^2\right\rangle_{T_{t,k}},$$
$$q=1,\ 2;\ k=1,\ \dots,\ N_{test};\ i=1,\ \dots,\ N_{ns}.$$

OR

$$v_{eval,k}(\omega_i) = \sqrt{\left\langle (H_{m,q}{}^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ \omega_i,\ t))^2\right\rangle_{T_{t,k}}},$$
$$q=1,\ 2;\ k=1,\ \dots,\ N_{test};\ i=1,\ \dots,\ N_{ns}.$$

S113

CANDIDATE UNIT VECTOR HAVING MINIMUM ONE OF FOLLOWING VARIANCE IS SELECTED AS DIRECTION OF NOUSE MAGNETIC FIELD

$$\mathrm{var}(\omega_i) = \frac{\sqrt{\mathrm{mean}_k((v_{eval,k}(\omega_i) - \mathrm{mean}_k(v_{eval,k}(\omega_i)))^2)}}{\mathrm{mean}_k(v_{eval,k}(\omega_i))},\ i=1,\ \dots,\ N_{ns}.$$

END

FIG.22

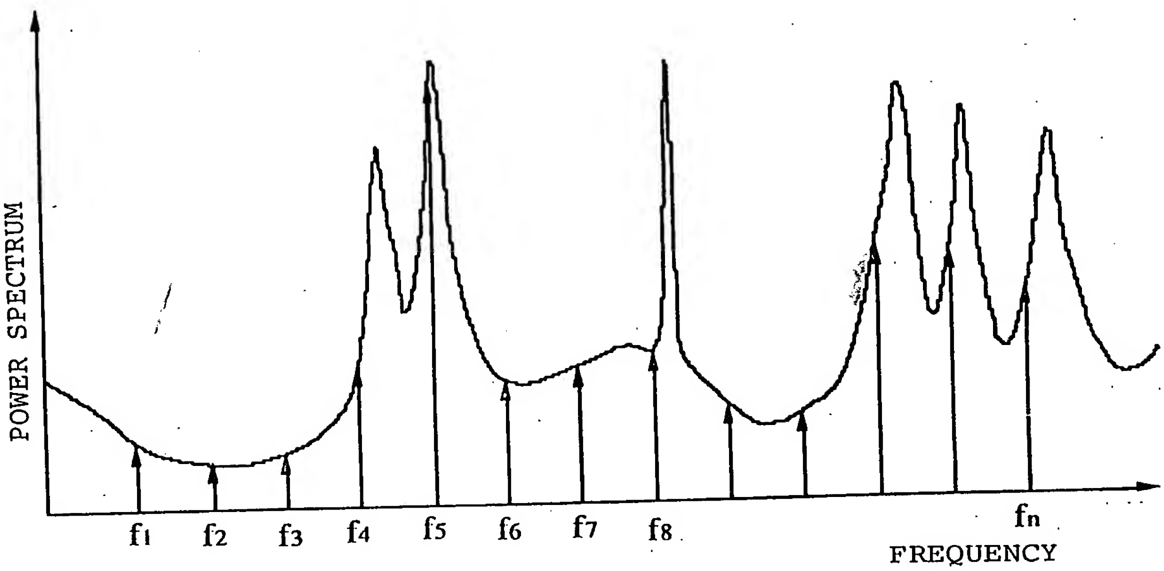


FIG.23

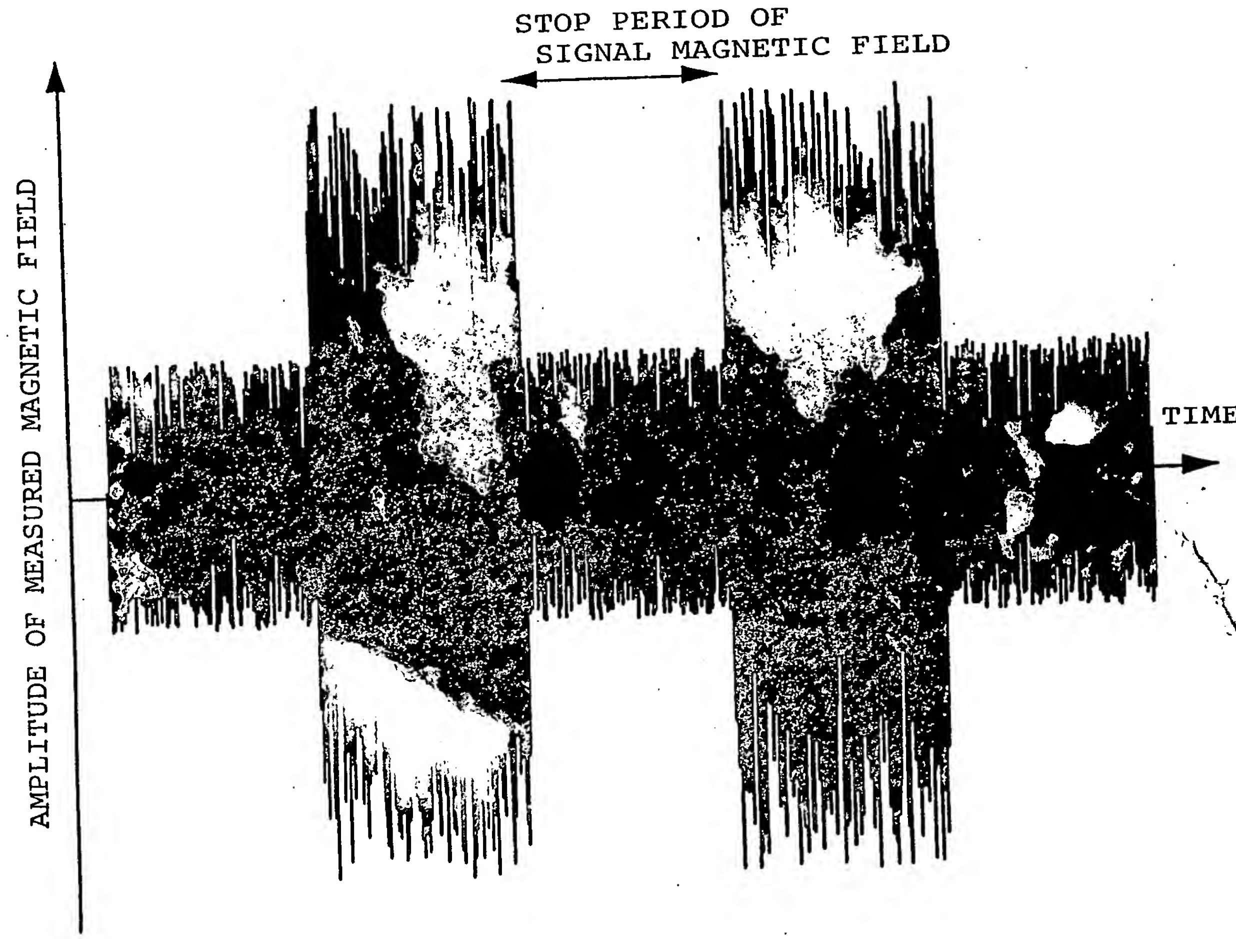

STOP PERIOD OF
SIGNAL MAGNETIC FIELD
AMPLITUDE OF MEASURED MAGNETIC FIELD
TIME

FIG.24

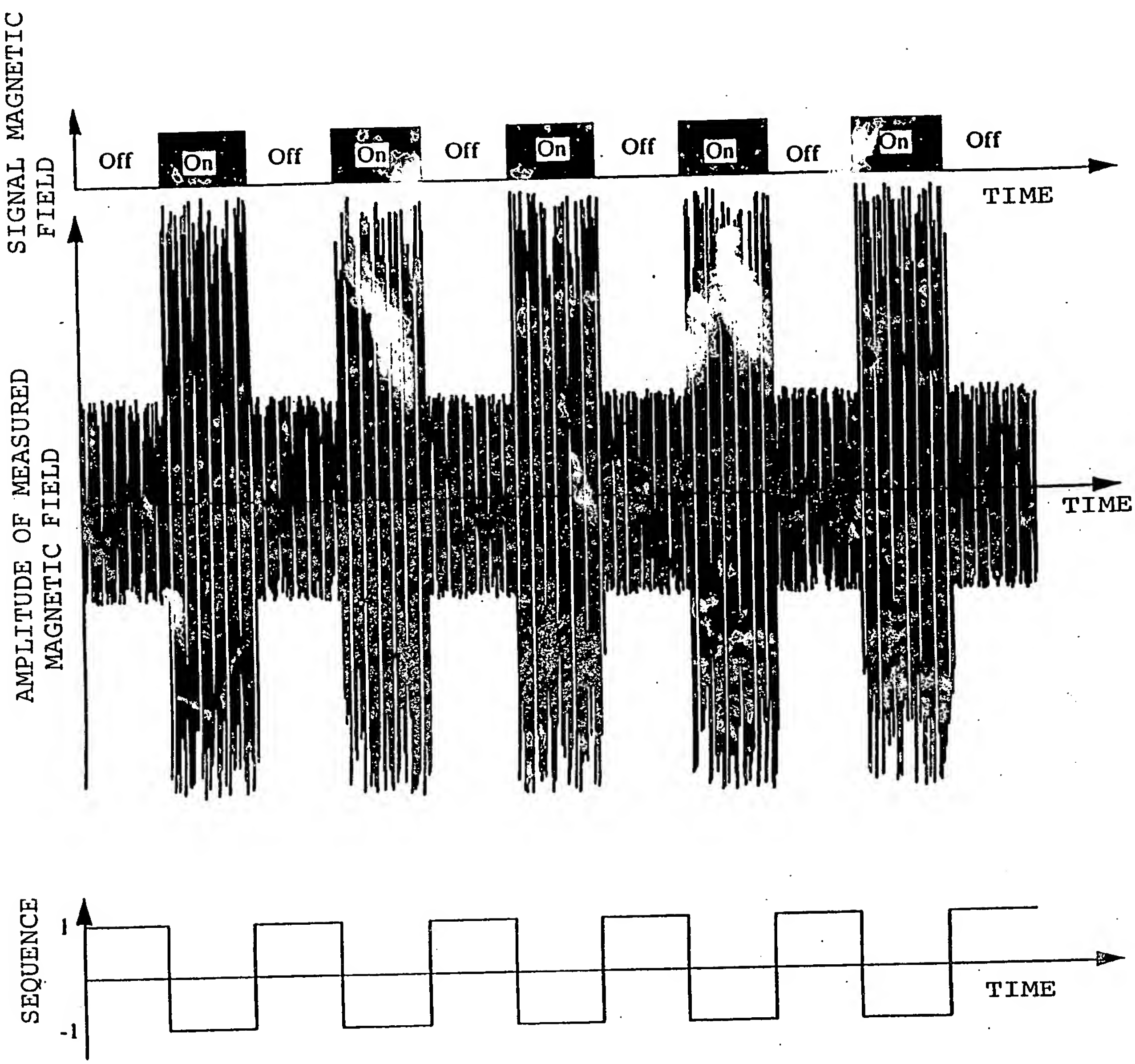

SIGNAL MAGNETIC FIELD
Off
On
Off
On
Off
On
Off
On
Off
On
Off
TIME
AMPLITUDE OF MEASURED MAGNETIC FIELD
TIME
SEQUENCE
1
-1
TIME

FIG.25

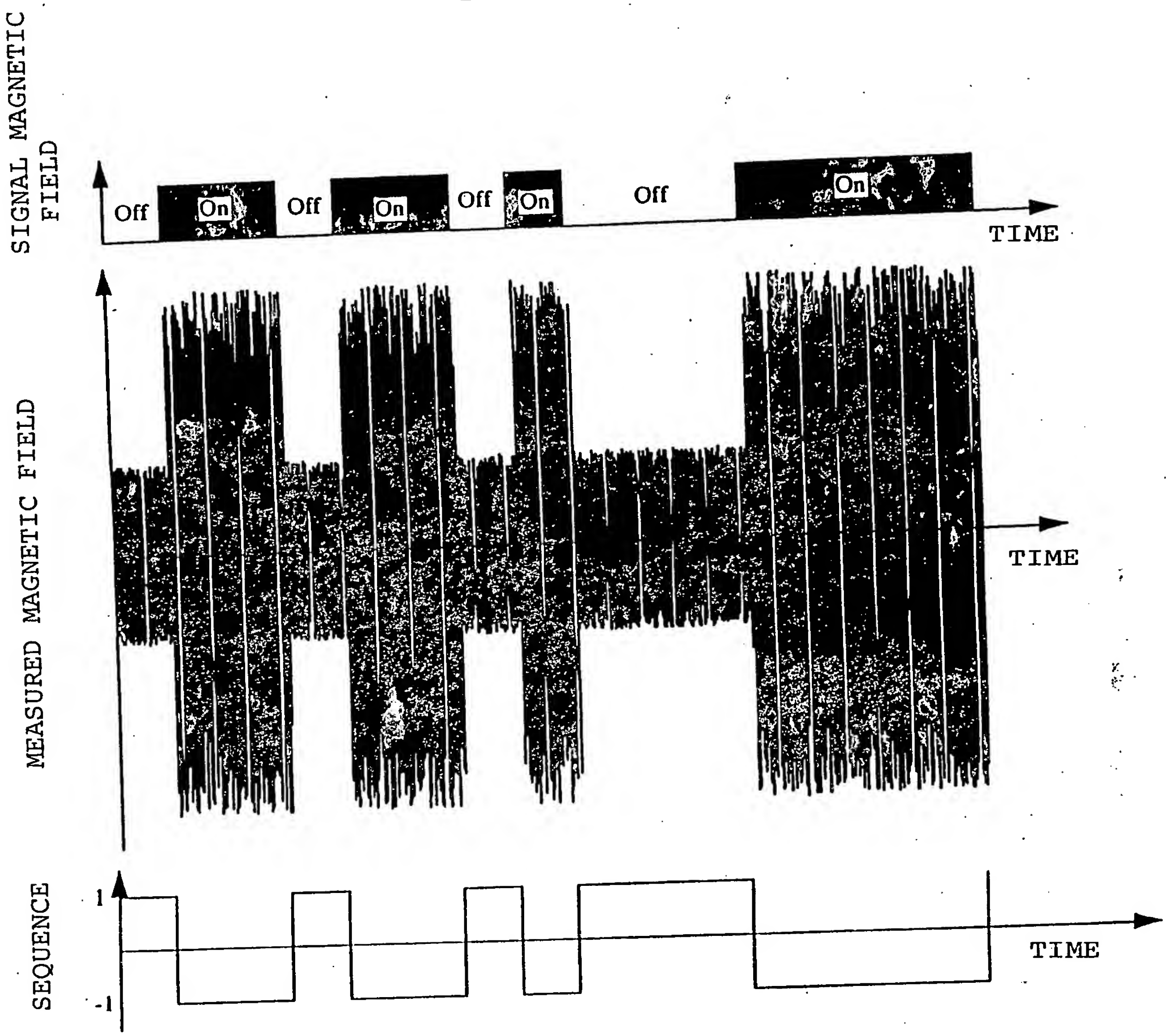

SIGNAL MAGNETIC FIELD
Off
On
Off
On
Off
On
Off
On
TIME
MEASURED MAGNETIC FIELD
TIME
SEQUENCE
1
-1
TIME

FIG.26

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S121
DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S122
MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S123
CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R(\tau)=\int_{t_k}^{t_k+N_T T_{period}}\left|\mathbf{H}_m(\mathbf{r}-\mathbf{r}_o,\ \theta_o,\ t)\right|s(t-\tau)dt.$$

OR

$$R(\tau)=\int_{t_k}^{t_k+N_T T_{period}}\sqrt{\left(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\,s(t-\tau)dt.$$

OR

$$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{period}}\left|H_{m,\alpha}(\mathbf{r}-\mathbf{r}_o,\ \theta_o,\ t)\right|s(t-\tau)dt,\ \alpha=x,y,z.$$

OR

$$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{period}}\sqrt{\left(H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\,s(t-\tau)dt,\ \alpha=x,y,z.$$

S124
TIME $\tau=t_{sync}$ WHERE CORRELATION $R(\tau)$ or $R_\alpha(\tau)$ BECOMES MAXIMUM IS OBTAINED

S125
TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS IDENTIFIED BY SEQUENCE $s(t-t_{sync})$

S126
TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.27

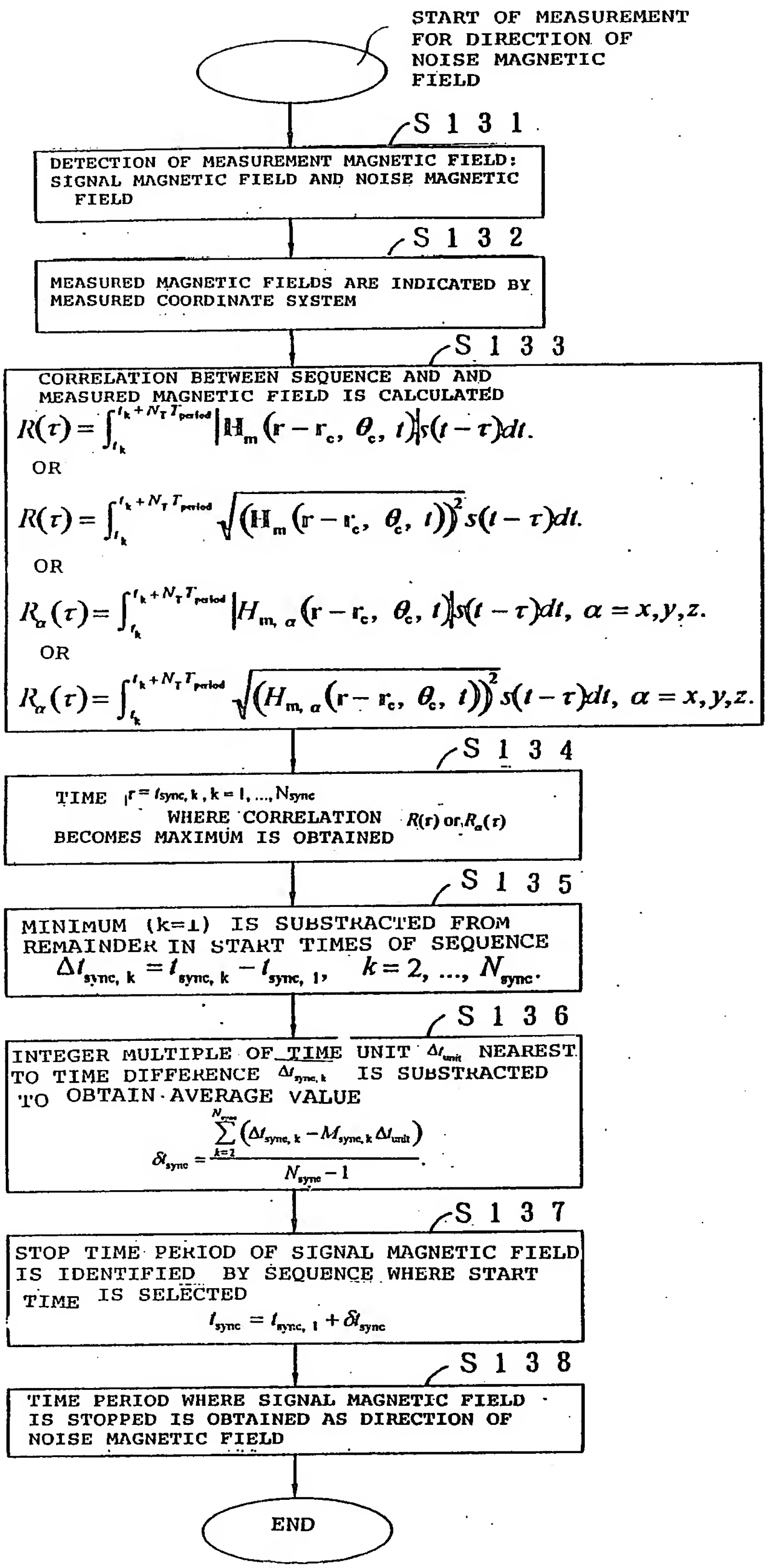

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD
S131
DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD
S132
MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM
S133
CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED
$R(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \left|\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right| s(t-\tau)dt.$
OR
$R(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \sqrt{\left(\mathbf{H}_m(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\, s(t-\tau)dt.$
OR
$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \left|H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right| s(t-\tau)dt,\ \alpha=x,y,z.$
OR
$R_\alpha(\tau)=\int_{t_k}^{t_k+N_T T_{period}} \sqrt{\left(H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\, s(t-\tau)dt,\ \alpha=x,y,z.$
S134
TIME $\tau=t_{sync,k},\ k=1,\ldots,N_{sync}$ WHERE CORRELATION $R(\tau)$ or $R_\alpha(\tau)$ BECOMES MAXIMUM IS OBTAINED
S135
MINIMUM (k=1) IS SUBSTRACTED FROM REMAINDER IN START TIMES OF SEQUENCE
$\Delta t_{sync,k}=t_{sync,k}-t_{sync,1},\quad k=2,\ldots,N_{sync}.$
S136
INTEGER MULTIPLE OF TIME UNIT Δt_{unit} NEAREST TO TIME DIFFERENCE $\Delta t_{sync,k}$ IS SUBSTRACTED TO OBTAIN AVERAGE VALUE
$\delta t_{sync}=\dfrac{\sum_{k=2}^{N_{sync}}\left(\Delta t_{sync,k}-M_{sync,k}\Delta t_{unit}\right)}{N_{sync}-1}.$
S137
STOP TIME PERIOD OF SIGNAL MAGNETIC FIELD IS IDENTIFIED BY SEQUENCE WHERE START TIME IS SELECTED
$t_{sync}=t_{sync,1}+\delta t_{sync}$
S138
TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD
END

FIG.28

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S141

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S142

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S143

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\left|H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right|s(t-t_k)dt,\quad k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$$

OR

$$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\sqrt{\left(H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\,s(t-t_k)dt,\quad k=1,\ldots,\ N_{div};\ \alpha=x,y,z.$$

BUT

$$t_k=t_0+k\cdot T_{div},\quad k=1,\ \ldots,\ N_{div}.$$

$$S_{mp}(t)=S(t+T_{period})$$

$$S_{mp}(t)=s(t),\quad 0\le t<T_{period}.$$

S144

PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR

$$\mathbf{e}_n(t_k)=\left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k=1,\ \ldots,\ N_{div}.$$

OF CORRELATION $R_\alpha(t_k),\ k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$

IS OBTAINED

$$\mathbf{H}_m^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t),\ k=1,\ \ldots,\ N_{div}.$$

S145a

t_k IS CALCULATED SO THAT VARIANCE

$$\mathrm{var}(t_k)=\frac{\sqrt{\left\langle\left(\mathbf{H}_m^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)-\left\langle\left|\mathbf{H}_m^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t\right)^2\right\rangle_t}}{\left\langle\left|\mathbf{H}_m^P(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t},\quad k=1,\ \ldots,\ N_{div}.$$

IS MINIMUM OR LESS THAN DETERMINED VALUE

$$\mathbf{e}_n(t_k)=\left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k=1,\ \ldots,\ N_{div}.$$

CORRESPONDING TO t_k IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.29

START O EASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S141

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S142

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S143

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\left|H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right|s(t-t_k)dt,$$
$$k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$$

OR

$$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\sqrt{\left(H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\,s(t-t_k)dt,$$
$$k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$$

BUT

$$t_k=t_0+k\cdot T_{div},\quad k=1,\ \ldots,\ N_{div}.$$
$$S_{mp}(t)=S(t+T_{period})$$
$$S_{mp}(t)=s(t),\quad 0\le t<T_{period}.$$

S144

PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR

$$\mathbf{e}_n(t_k)=(R_x(t_k)\ R_y(t_k)\ R_z(t_k))\ k=1,\ \ldots,\ N_{div}.$$

OF CORRELATION $R_\alpha(t_k),\ k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$

IS OBTAINED

$$\mathbf{H}_m^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t),\ k=1,\ \ldots,\ N_{div}.$$

S145b

tk IS CALCULATED SO THAT FOR VARIANCE

$$\mathrm{var}_\alpha(t_k)=\frac{\sqrt{\left\langle\left(H_{m,\alpha}^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)-\left\langle H_{m,\alpha}^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right\rangle_t\right)^2\right\rangle_t}}{\left\langle\left|\mathbf{H}_m^{P}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t},$$
$$\alpha=x,\ y,\ z;\ k=1,\ \ldots,\ N_{div}.\ -1,\ \ldots,\ N_{div}.$$

$$\sum_{\alpha=x,y,z}\mathrm{var}_\alpha(t_k)$$

OR

$$\sqrt{\sum_{\alpha=x,y,z}\left(\mathrm{var}_\alpha(t_k)\right)^2}.$$

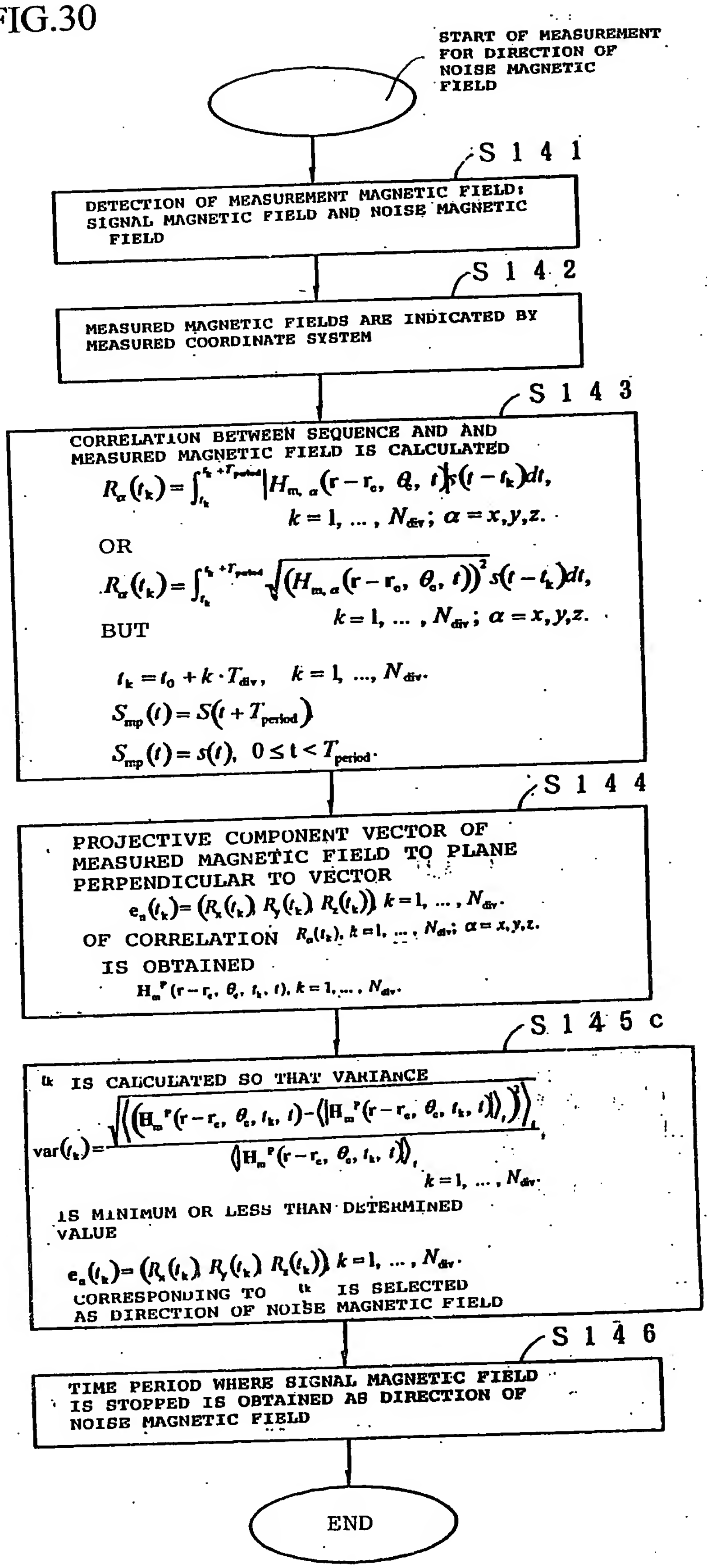
IS MINIMUM OR LESS THAN DETERMINED VALUE

$$\mathbf{e}_n(t_k)=(R_x(t_k)\ R_y(t_k)\ R_z(t_k))\ k=1,\ \ldots,\ N_{div}.$$

CORRESPONDING TO tk IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.30



START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD
S141
DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD
S142
MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM
S143
CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED
$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\left|H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right|s(t-t_k)dt,\quad k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$
OR
$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\sqrt{\left(H_{m,\alpha}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t)\right)^2}\,s(t-t_k)dt,\quad k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$
BUT
$t_k=t_0+k\cdot T_{div},\quad k=1,\ \ldots,\ N_{div}.$
$S_{mp}(t)=S(t+T_{period})$
$S_{mp}(t)=s(t),\ 0\le t<T_{period}.$
S144
PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR
$\mathbf{e}_n(t_k)=\left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k=1,\ \ldots,\ N_{div}.$
OF CORRELATION $R_\alpha(t_k),\ k=1,\ \ldots,\ N_{div};\ \alpha=x,y,z.$
IS OBTAINED
$\mathbf{H}_m^{\ p}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t),\ k=1,\ \ldots,\ N_{div}.$
S145c
t_k IS CALCULATED SO THAT VARIANCE
$\mathrm{var}(t_k)=\dfrac{\sqrt{\left\langle\left(\mathbf{H}_m^{\ p}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)-\left\langle\left|\mathbf{H}_m^{\ p}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t\right)^2\right\rangle_t}}{\left\langle\left|\mathbf{H}_m^{\ p}(\mathbf{r}-\mathbf{r}_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t},\quad k=1,\ \ldots,\ N_{div}.$
IS MINIMUM OR LESS THAN DETERMINED VALUE
$\mathbf{e}_n(t_k)=\left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k=1,\ \ldots,\ N_{div}.$
CORRESPONDING TO t_k IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD
S146
TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD
END

FIG.31

START OF MEASUREMENT FOR DIRECTION OF NOISE MAGNETIC FIELD

S141

DETECTION OF MEASUREMENT MAGNETIC FIELD: SIGNAL MAGNETIC FIELD AND NOISE MAGNETIC FIELD

S142

MEASURED MAGNETIC FIELDS ARE INDICATED BY MEASURED COORDINATE SYSTEM

S143

CORRELATION BETWEEN SEQUENCE AND AND MEASURED MAGNETIC FIELD IS CALCULATED

$$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\left|H_{m,\alpha}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t)\right|s(t-t_k)dt,\quad k=1,\ldots,N_{div};\ \alpha=x,y,z.$$

OR

$$R_\alpha(t_k)=\int_{t_k}^{t_k+T_{period}}\sqrt{\left(H_{m,\alpha}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t)\right)^2}\,s(t-t_k)dt,\quad k=1,\ldots,N_{div};\ \alpha=x,y,z.$$

BUT

$$t_k=t_0+k\cdot T_{div},\quad k=1,\ldots,N_{div}.$$

$$S_{mp}(t)=S(t+T_{period})$$

$$S_{mp}(t)=s(t),\ 0\leq t<T_{period}.$$

S144

PROJECTIVE COMPONENT VECTOR OF MEASURED MAGNETIC FIELD TO PLANE PERPENDICULAR TO VECTOR

$$\mathrm{e}_n(t_k)=\left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k=1,\ldots,N_{div}.$$

OF CORRELATION $R_\alpha(t_k),\ k=1,\ldots,N_{div};\ \alpha=x,y,z.$

IS OBTAINED

$$\mathrm{H}_m^{\ P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t),\ k=1,\ldots,N_{div}.$$

S145d

t_k IS CALCULATED SO THAT FOR VARIANCE

$$\mathrm{var}_\alpha(t_k)=\frac{\sqrt{\left\langle\left(H_{m,\alpha}^{\ P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t)-\left\langle H_{m,\alpha}^{\ P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t)\right\rangle_t\right)^2\right\rangle_t}}{\left\langle\left|\mathrm{H}_m^{\ P}(\mathrm{r}-\mathrm{r}_c,\ \theta_c,\ t_k,\ t)\right|\right\rangle_t},\quad 1,\ldots,N_{div}.$$

$$\alpha=x,\ y,\ z,\ k=1,\ldots,N_{div}.$$

$$\sum_{\alpha=x,y,z}\mathrm{var}_\alpha(t_k)$$

OR

$$\sqrt{\sum_{\alpha=x,y,z}\left(\mathrm{var}_\alpha(t_k)\right)^2}.$$

IS MINIMUM OR LESS THAN DETERMINED VALUE

$$\mathrm{e}_n(t_k)=\left(R_x(t_k)\ R_y(t_k)\ R_z(t_k)\right)\ k=1,\ldots,N_{div}.$$

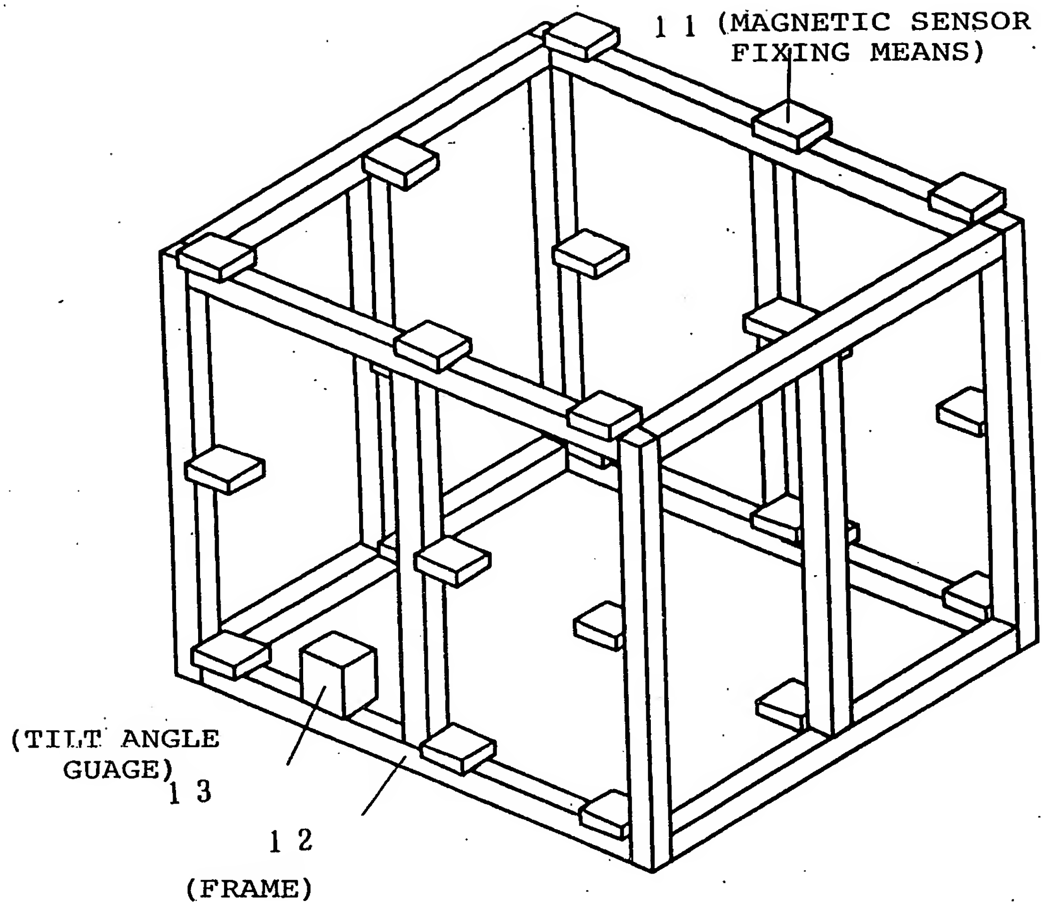
CORRESPONDING TO t_k IS SELECTED AS DIRECTION OF NOISE MAGNETIC FIELD

S146

TIME PERIOD WHERE SIGNAL MAGNETIC FIELD IS STOPPED IS OBTAINED AS DIRECTION OF NOISE MAGNETIC FIELD

END

FIG.32


11 (MAGNETIC SENSOR FIXING MEANS)
(TILT ANGLE GUAGE) 13
12
(FRAME)